TRANSACTIONS OF THE INSTITUTE OF AVIATION ISSN 0509-6669
No. 4 (245), pp. 60-69, Warsaw 2016 eISSN 2300-5408
DOI: 10.5604/05096669.1226356

COMPOSITE TESTING LABORATORY PERFORMANCE DEVELOPMENT BASED ON LEAN SIGMA APPROACH – CASE STUDY

Konrad Kozaczuk, Małgorzata Zalewska

Centre for Composite Technologies, Institute of Aviation, Al. Krakowska 110/114, 02-256 Warsaw
konrad.kozaczuk@ilot.edu.pl, malgorzata.zalewska@ilot.edu.pl

Abstract

The paper presents a case study describing the implementation of a Lean Sigma methodology to the Composite Testing Laboratory (CTL) of Centre for Composite Technologies of the Warsaw Institute of Aviation (WIA) in order to develop the overall performance and meet customer requirements. The article presents general requirements associated with composite testing and Lean Sigma technique as a combination of two well-known quality improvement methodologies which rely on waste and production cycle time reduction (Lean) as well as quality improvement and incremental reduction of defects (Six Sigma). The whole process of Lab improvement is depicted using the Six Sigma structured method DMAIC (Define, Measure, Analyse, Improve, Control). Each phase shows the actions that were undertaken with customer and management support from 2014 to 2015 as well as the Lean Sigma tools that were applied. Conclusions show the improvements that were observed in CTL after the project accomplishment and the experiences gained.
Keywords: composite testing, Lean Sigma, Six Sigma, DMAIC.

1. INTRODUCTION

CTL was created with the aim of providing advanced tests on composite materials. Due to the fact that nowadays composites are widely used in the manufacturing airframe primary and secondary structures, CTL became the focus of attention of western airframers [1]. Those days the Lab was not ready to provide reliable, high volume tests of composite materials according to regulatory agencie requirements. There was a need to widen tests scope, improve the quality of the existing processes and streamline the activities such as coupons cutting, tab bonding and reporting. Thanks to employees, management and customer engagement, CTL used Lean Sigma tools and managed to implement the necessary tests methods and increase the quality and speed of testing.

The authors want to show that Lean Sigma methodology can be easily applied not only in the manufacturing sector, but also in the lab where the number of factors that may influence test results is high [2]. The presented case study might be an example and inspiration for the reader to apply Lean Sigma tools in their own work environment.

2. GENERAL REQUIREMENTS FOR COMPOSITE TESTING

Requirements related to airworthiness of aircraft products are defined by Regulatory Agencies such as the FAA (Federal Aviation Administration) or EASA (European Aviation Safety Agency) in their official Regulations (i.e. 14 CFR Part 25, Transport Category Airplanes). In the process of structure certification, the airframe manufacturer may go through the building block approach, presented in figure 1. This approach assumes program of tests and analysis on coupon, element, detail, sub-component and component level to substantiate that the structure exposed to defined loads and environmental conditions is airworthy [3].

The role of CTL is to perform coupon and element level mechanical tests for aviation industry, as it is outlined in Figure 1, as well as physical and chemical tests [4]. The Lab must provide reliable tests results that can be applied for design values determination or their validation.

The biggest challenge for any composite lab is to generate test results with minimum variability. The most common sources of variability include: material defects (i.e. void content), improper cutting (inadequate coupon surface preparation), improper material storing, lack of system for coupon identification, improper tabbing, poor quality of the hole in coupons, non-axial strain gauge location, non-calibrated testing equipment, nonstandard test fixtures, poor test frame alignment, test operator or calculation errors.

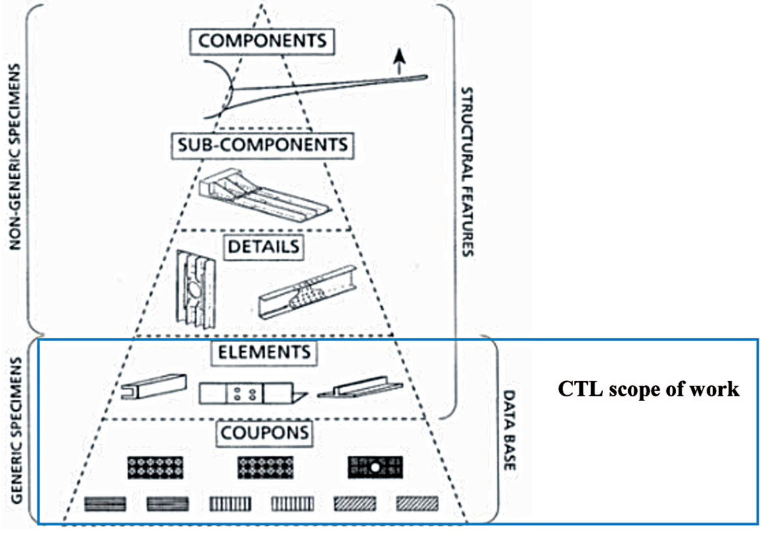

Fig. 1. Schematic diagram of building block tests for a fixed wing [5]

3. LEAN SIX SIGMA METHODOLOGY OVERVIEW

Lean Six Sigma methodology brings together two well-known management strategies: Six Sigma and Lean. Although both strategies were originally created only for manufacturing companies, recent years have shown that there is a need and tendency to go beyond the manufacturing sector and apply Lean Sigma in other fields. A good example of its implementation is Lockheed Martin and their LM21 operational excellence program [6].

Six Sigma is a data driven methodology, focused on quality improvement and process variation elimination. The goal can be obtained by using statistical tools and a deep understanding of the processes. There is a five-step approach for improving the process and achieving more reliable and predictable results: Define, Measure, Analyze, Improve and Control (DMAIC). For designing a new product, service or process, due to many uncertainties, the use of DMEDI technique (Define, Measure, Explore, Develop, Implement) [7] would be more applicable.

Lean, on the other hand is focused on reduction of waste which is defined as non-value added activities and improving the process speed [8]. There are 5 Lean principles:

1. Customer value which defines the value which the customer is willing to pay for. In the Lab those are reliable tests results with an acceptable failure mode and satisfactory coefficient of variation.
2. Value stream which determines work required to bring a service from the customer's request to the customer's satisfaction. In terms of the Lab activity, the value stream starts with material delivery, through coupons preparation, testing and ends with reporting (figure 2).

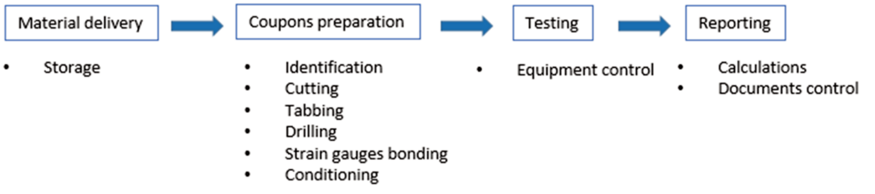

Fig. 2. Activities that have an impact on final tests results. Source: [own elaboration]

3. Flow which creates efficient flow of work, any delay is a waste. Considering the Lab activity this is a system of testing that satisfies customer as well as the employees. It allows for continuous growth and a solution to the issues that may appear.
4. Pull which begins work on demand, and adjust capabilities to the customer's specifications. Regarding the Lab activities the pull system is daily work where each step of testing depends on the output of the previous one, as well as any implementation of a new test method that is needed by the customer.
5. Perfection which continually improves the process of delivering, for example, test results on time without any defects or waste. That step is fulfilled by the Lab by constant examination of coupon preparation and testing in order to improve the quality as well as the efficiency of work.

4. DMAIC APPROACH FOR THE LAB PERFORMANCE IMPROVEMENT

Below is presented a description of the Lab development in the sequence of the five-phase problem solving tool – DMAIC. All the activities outlined below were initiated by the customer audit which resulted in clear and valuable feedback. Although there were several areas to be improved, fulfilling customer requirements was an opportunity to acquire large volume orders. Lean Sigma application and support of management helped to meet the customer needs and achieve the defined goals.

4.1. Define Step

The first action was to define the project. At that stage the management needed to make a few determinations:

1. what needs to be improved,
2. who will work on it,
3. what the overall strategy is going to be.

As answers to those questions were found, the main goal to improve CTL performance and capability to be able to execute commercial material testing was set. This meant developing the overall testing process and Lab work organization. A project team was selected and Lean Sigma approach as a method to execute the project.

The next step was to define the project CTQs (Critical to Quality), which are quality parameters related to customer's needs. In this case, the information was provided by the customer as the audit findings. The customer CTQs were:

1. reliable test results,
2. minor results variation,
3. complete test process documentation,
4. work done according to the schedule,
5. progress tracking,
6. all required test methods implemented,
7. undamaged coupons,
8. tests in all required environmental conditions,
9. proper coupons preparation.

Customer help at that stage of the project was significant. Thanks to the input, CTL could clearly define the customer needs and which of them have to be met by the Lab and what level of performance Lab wants to achieve. It also helped to understand the market of composite structure manufacturing, what the perspectives are and where a place for CTL is. It is worth mentioning here the well-known slogan of Lockheed Martin "We never forget who we work for". With this principle in mind the Lab took a challenge to exceed the customer expectations.

4.2. Measure Step

At the beginning of the measure phase there was a need to transfer the customer CTQs to measurable requirements for the Lab. Next, in order to understand the relationship between the CTQs and the developed requirements and evaluate what aspects are most important, as presented in figure 3, the "House of Quality" was created.

At the following stage performance objectives for each measurable CTQs were defined. The performance objectives are shown in table 1.

Table 1. Project performance objectives [own elaboration]

No	Measurable CTQs	Performance objectives
1	Employees competences	Min. 2 employees rated for 4 (1÷5 scale) for each test method and defined skill
2	Coupons conditioning capability	Chamber and conditioning process introduced
3	Wet grinding	Grinder and grinding process introduced
4	Testing procedures	Testing procedures internally approved for all implemented test methods
5	Cutting quality	Coupon dimensions according to drawing tolerances, no cutting saw marks on coupon surface
6	Strain gauging process	Strain gauging procedure introduced for coupons testing in RTA (Room Temperature Ambient) and ETW (Elevated Temperature Wet) conditions
7	Approved procedure for tabs bonding	Customer approved procedure for tabs bonding incorporated
6	Quality checks	Introduced documented quality control at defined check points
9	Approved test fixtures	All text fixture approved by the customer
10	Equipment control	100% equipment calibrated
11	Work organization	Each employee has defined task for each working day
12	Progress monitoring incorporation	Project tracking system introduced

Requiremnets/ measurable CTQs Relationship (1-9) Customer CTQs	Importance (1-5)	Employees competences	Cutting quality	Wet grinding	Aproved procedure for tabs bonding	Coupons conditioning capability	Strain gauging process	Testing procedures	Work organization	Progress monitoring incorporation	Approved test fixtures	Equipment control	Quality checks
Reliable tests results	5	9	9	9	9	9	9	7	7		9	9	9
Minor results variation	4	9	9	9	9	9	5	7			9	9	9
Complete test process documentation	4	5	3	5	5	5		5	9	3		9	7
Work done according to the schedule	3	5	5	5		3				9	5		
Progress tracking	4	4								9			
All required test methods implemented	5	9						7			9		
No damaged coupons	3	7	5	5	5	3	3	9					
Test in all required environmental conditions	5	9				9	9						
Proper coupons preparation	4	9	9	9	9	9	9	5	7				9
Priority		279	159	167	152	200	155	165	99	75	141	117	145
Targert values		15%	9%	9%	8%	11%	8%	9%	5%	4%	8%	6%	8%

Fig. 3. QFD for the Lab performance development [own elaboration]

The analysis in figure 3 resulted in the requirements evaluation. The list below presents the measurable CTQs starting with the highest rated one.

1. employees competences,
2. coupons conditioning capability,
3. wet grinding,
4. testing procedures,
5. cutting quality,
6. strain gauging process,
7. approved procedure for tabs bonding,
8. quality checks,
9. approved test fixtures,
10. equipment control,
11. work organization,
12. progress monitoring incorporation.

4.3. Analysis Step

In order to evaluate the baseline Lab performance and properly understand the problem causes a need arose to gather data. For each defined measurable CTQ an approach was chosen to analyze the current process capability. Baseline process performance is shown in table 2.

Table 2. Baseline process performance [own elaboration]

No	Measurable CTQs	Measure method	Baseline performance
1	Employees competences	Survey	For most test methods and skills max 1 employee rated for 4 (1÷5 scale)
2	Coupons conditioning capability	YES/NO	NO
3	Wet grinding	YES/NO	NO
4	Testing procedures	Count	4 procedures from 12 required
5	Cutting quality	Acceptable/non acceptable	Non acceptable by the customer
6	Strain gauging process	YES/NO	NO, Process introduced only for coupons testing in RTA condition
7	Approved procedure for tabs bonding	YES/NO	NO, Process approved only for 1 from 2 required tests methods
6	Quality checks	Count	1 quality check defined
9	Approved test fixtures	Count	6 from 12
10	Equipment control	YES/NO	100 % equipment calibrated
11	Work organization	YES/NO	NO, No specified laboratory work for each day
12	Progress monitoring incorporation	YES/NO	NO system for progress monitoring

At that stage of the project the Lab baseline performance for each CTQ in relation to the Lab objectives and customer expectations was defined. The next step was to identify root causes of poor performance and address them.

In order to verify employee competences a survey was performed to evaluate each employee according to specified test methods and the defined set of skills. At first, an employee assessed himself, then his manager verified this rating. The results of the survey showed low team competences and a need for improvements in the field of coupons cutting, strain gauging, tabs bonding and test machines operating.

Customer requirements measured with YES/NO method were relatively easy to meet. Conditioning chamber and grinder parameters were defined. Requirements for strain gauging and tabbing processes were also determined with customer cooperation. A similar approach was taken to testing procedures and text fixtures.

Poor cutting quality was related to the technique implemented in the Lab, which used only a diamond wheel. Microscope inspection clearly showed the saw marks on the coupon edge, which were not accepted by the customer. An example of the cutting quality, before the improvements which have been incorporated, is shown in figure 4.

Fig. 4. Quality of the diamond wheel coupon cutting [own elaboration]

Lacks in the field of testing progress monitoring and quality checks were related to general work organization.

Based on this analysis and understanding the project team was ready to move to the Improve Step.

4.4. Improve Step

In the Improve Step, CTL implemented a number of improvements referred to as quality and efficiency increases as well as defects and waste reduction. All the applied changes corresponded to the defined customer needs.

The phase was started with a creation of a detailed plan for meeting the determined objectives. It included project team definition with the team members' roles and responsibilities, the project scope with actions for improving the existing processes and implementing new testing methods, a schedule for the plan execution and the customer involvement. Additionally, a risk register was created along with the risk mitigations and contingency and communication plan referring to the project team, sponsor and the customer. In figure 5, the initial project schedule (part of the whole improvement plan) is shown.

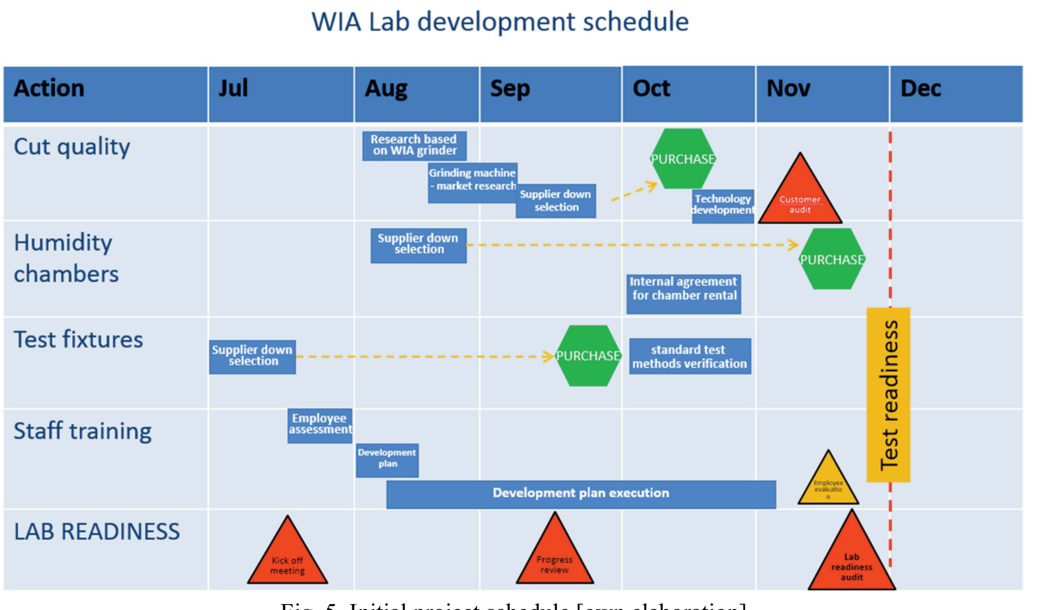

Fig. 5. Initial project schedule [own elaboration]

The most challenging aspect of the plan was staff training. First of all, the processes related to coupon preparation and testing were documented in written procedures. During the implementation of new test methods the employees were trained on three levels. The first training was run by the test procedure owner who presented the test method and the standard requirements. The second training was performed by the customer who indicated critical factors, tests sensitivity and additional test requirements. In the last one, employees participated in "on-the-job training". For each new test method introduced round robin tests were carried out. After achieving results consistency the Lab was deemed able to perform particular test methods. Every month a survey was conducted to verify the team progress.

The CTQ concerning coupon preparation quality and wet grinding technology were strictly related. Figure 6 shows an example how the quality of composite coupon surface was improved. This is the result of work on custom designed fixtures, grinder implementation and documented procedures.

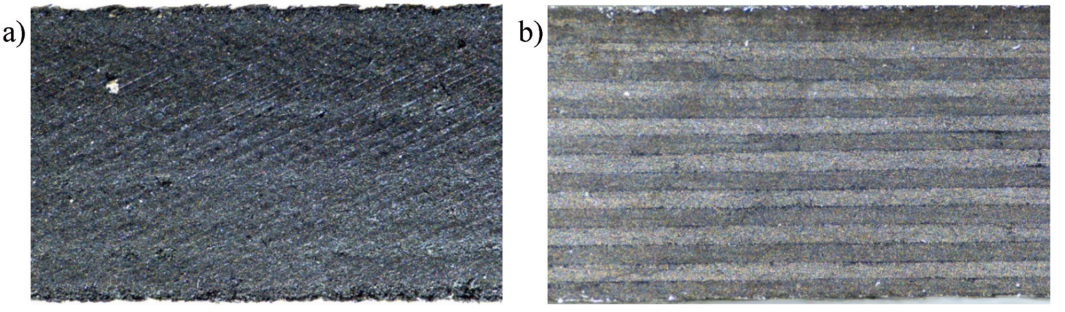

Fig. 6. Composite coupon surface: a) without, b) with wet grinding [own elaboration]

Other significant changes concerned the implementation of the conditioning chamber with controlled temperature and humidity, paste adhesive tabs bonding, strain gauges bonding for hot/wet testing and, which is very significant, an introduction of several mechanical and physio-chemical tests methods for composite materials.

All the actions performed in this phase were supported by the top management, controlled by the certified Black Belt (a professional with leadership skills and project management experience) and tracked in the spreadsheet. This allowed to see the progress and continually provide updated information to the customer.

4.5. Control Step

The main idea of the Control Step is to ensure that all the improvements obtained in previous Steps are maintained. The first phase of the Control Step is a repeat of the process capability analysis, the results are shown in table 3.

Table 3. Process performance after improvements [own elaboration]

No	Measurable CTQs	Measure method	Performance after improvements
1	Employees competences	Survey	For all implemented test methods and skills max at least 2 employee rated for 4 (1÷5 scale)
2	Coupons conditioning capability	YES/NO	YES
3	Wet grinding	YES/NO	YES
4	Testing procedures	Count	10 procedures from 12 required
5	Cutting quality	Acceptable/non acceptable	Acceptable cutting quality
6	Strain gauging process	YES/NO	YES, Implemented procedures for strain gauging for RTA and ETW conditions
7	Approved procedure for tabs bonding	YES/NO	YES, Approved procedures for 2 required tests methods
6	Quality checks	Count	3 quality checks defined
9	Approved test fixtures	Count	10 from 12
10	Equipment control	YES/NO	100 % equipment calibrated
11	Work organization	YES/NO	YES, system for daily tasks developed
12	Progress monitoring incorporation	YES/NO	All open programs tracked

Analysis showed significant progress. Since learning and improvement processes are always continuous, small variations of the project goals were acceptable at this point with an aim to meet all the requirements in the next 6 months.

At that point a process control was defined to keep the achieved performance. In the Lab work environment it is worth monitoring a few metrics that give an overview of added-value and non-added value activities [6].

The first metric is the "work in process". In the Lab it refers to the work that has been started and not completed regarding open orders, test programs, coupons preparation and testing. The second metric is an "average completion rate". In the Lab it defines how many coupons were prepared and what kind of tests were done within the determined time frame. The third metric monitored in the Lab is "demanded variation", determining how the process output differs from the demand. In the Lab there are specified expectations for a defined period of time regarding the number and type of coupons which need to be prepared and tested.

For understanding the wastes in the processes, it is recommended to look at the setups and downtime. Since the Lab scope of work is wide, there was much work related to setups of the cutting machine, grinder or test frame. There are also equipment breakdowns that generate downtime.

Another metric for the performance assessment is the number of defects. In the Lab this concerns, for example, the number of destroyed coupons in the process of preparation, inconsistency in the inter-laboratory comparison or errors in material properties calculations. In order to streamline the processes, it is also important to understand and measure testing complexity. Through the Lab development it was proven that the best and easiest solutions to put under control are the simplest ones. The last important metric that determines the overall Lab capabilities are the Lab team competences. There are the Lab quality system requirements to gather data regarding each employee's qualifications referred to particular skills and tests methods as well as authorizations.

5. CONCLUSIONS

Based on the performed work the following conclusions can be drawn:

- application of Lean Sigma methodology, and especially the DIMAC approach, helped the Composite Testing Laboratory of Centre for Composite Technologies of the Institute of Aviation to achieve world-class level of performance. It means this Lab was granted several orders for material testing with an application to aircraft structures certified with FAR 25 requirements,
- the accomplishment of training significantly improved the Lab team competences, currently at least 2 employees can perform individually each implemented test method,
- wet grinding and customized fixtures for diamond wheel cutting deployment resulted in customer acceptance of coupon preparation quality,
- based on carried out round robin tests the Lab achieved customer authorization to carry out 12 tests methods,
- created room for material and coupon storage ensures that delivered customer material is kept in order,
- internal procedures approved by the customer ensure that the coupons preparation and testing are repetitive and reliable,
- in the first 6 months of work, when there was a significant increase of testing rate, several cases of equipment breakdown were observed. Based on that experience, in the future, in order to avoid working under the pressure and minimize machine idle time equipment breakdown will be incorporated in risk register and monitored,
- after new procedures incorporation and starting testing execution it was noticed that real testing rate was 20 % lower than estimated. Detail time measurement of process steps showed unoptimal resources allocation and the lack of some basic equipment. In the future, while implementing new tests methods testing process simulation will be performed in order to optimize resources allocation and address supporting hardware needs.

BIBLIOGRAPHY

[1] Piwek K., Wiśniowski W., 2016, „Small air transport aircraft entry requirements evoked by FlightPath 2050", Aircraft Engineering and Aerospace Technology, Vol. 88, Issue 2, pp. 341-347.
[2] Iwaniuk A., Wiśniowski W. and Żółtak J., 2016, "Multi-disciplinary optimization approach for a light turpoprop aircraft-engine integration and improvement", Aircraft Engineering and Aerospace Technology, Vol. 88, Issue 2, pp. 348-355.
[3] Piwek K., 2004, "The certification process of I-23 "Manager" Aircraft", Transactions of the Institute of Aviation, Special Edition.
[4] CMH-17, 2012, "Composite Materials Handbook, Volume 1. Polymer Matrix Composites Guidelines for Characterization of Structural Materials" SAE International.
[5] European Aviation Safety Agency, 2010, "AMC 20-29 Composite Aircraft Structure".
[6] Joyce M., Schechter B., 2004, "The lean enterprise – A management philosophy at Lockheed Martin",Office of the Under Secretary of Defense for Acquisition Technology & Logistics.
[7] George M. L., 2003, "Lean Sigma for Service", New York: The McGraw-Hill Companies.
[8] Michael Allen**,** Lean Sigma in the Lab, Retrieved October 20, 2015 from http://www.labautopedia.org/mw/Lean_Sigma_in_the_lab.

ROZWÓJ LABORATORIUM BADAŃ KOMPOZYTÓW W OPARCU O METODYKĘ LEAN SIGMA – STUDIUM PRZYPADKU

Streszczenie

Artykuł prezentuje studium przypadku opisujące wdrożenie metodyki Lean Sigma w Laboratorium Badań Kompozytów Centrum Technologii Kompozytowych, Instytutu Lotnictwa, w celu zwiększenia wydajności Laboratorium oraz spełnienia wymagań klienta. W artykule zostały przedstawione ogólne wymagania w zakresie badań kompozytów oraz technika Lean Sigma jako kombinacja dwóch dobrze znanych metodologii poprawy jakości, które opierają się na redukcji strat i czasu cyklu produkcyjnego (Lean) jak również poprawy jakości i stopniowej redukcji defektów (Six Sigma). Całościowy proces polepszenia Laboratorium jest opisany z użyciem metody DMAIC (Zdefiniuj, Zmierz, Zanalizuj, Usprawnij, Kontroluj). W każdej z faz opisane zostały akcje, które zostały podjęte przy wsparciu klienta oraz zarządu od 2014 do 2015 oraz narzędzia Lean Sigma jakie zostały użyte. W podsumowaniu zostały przedstawione ulepszenia Laboratorium po zakończeniu projektu oraz nabyte doświadczenia.
<u>Słowa kluczowe:</u> badania kompozytów, Lean Sigma, Sześć Sigma, DMAIC.